Heuristic Analysis

Bellow are the results and analysis of running uninformed and A* planning searches for the 3 air cargo problems:

1. Air Cargo Problem 1:

Air Cargo Problem 1							
	Search Algorithm	**Expansions**	**Goal Tests**	**New Nodes**	**Plan length**	**Time elapsed**	**Optimality of solution**
uninformed planning searches	breadth_first_search	43	56	180	6	0.05923	yes
	depth_first_graph_search	21	22	84	20	0.02769	No, It may find a non-optimal goal first
	uniform_cost_search	55	57	224	6	0.07083	yes
	greedy_best_first_graph_search with h_1	7	9	28	6	0.01067	yes
A* planning searches	astar_search with h_1	55	57	224	6	0.07174	yes
	astar_search with h_ignore_preconditions	41	43	170	6	0.07478	yes
	astar_search with h_pg_levelsum	11	13	50	6	0.83256	yes

Problem 1 Optimal plan:

```
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)
```

The best uninformed planning search for problem 1 appears to be the greedy best first graph search in term of all the mentioned metrics in the table above. But it may not be the case for larger space search as it may lead to unwanted expansions before reaching the optimal goal. Followed by the depth first search then breadth-first search with more new nodes and expansions.

A* planning search with h_ignore_preconditions is optimal in term of the time elapsed, but not in term of the expansion, goal tests and nodes. However, A* search with h_pg_levelsum is optimal in term of the order because it expand less nodes but with a cost of taking more time to execute.

2. Air Cargo Problem 2:

Air Cargo Problem 2							
	Search Algorithm	**Expansions**	**Goal Tests**	**New Nodes**	**Plan length**	**Time elapsed**	**Optimality of solution**
uninformed planning searches	breadth_first_search	3343	4609	30509	9	14.54061	yes
	depth_first_graph_search	624	625	5602	619	5.741592	No, It may find a non-optimal goal first
	uniform_cost_search	4849	4851	44001	9	20.781775	yes
	greedy_best_first_graph_search with h_1	966	968	8694	16	4.168545	yes
A* planning searches	astar_search with h_1	4849	4851	44001	9	21.013688	yes
	astar_search with h_ignore_preconditions	1443	1445	13234	9	7.622070	yes
	astar_search with h_pg_levelsum	85	87	831	9	67.865339	yes

Optimal plan:

Load(C1, P1, SFO)
Load(C2, P2, JFK)
Load(C3, P3, ATL)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Fly(P3, ATL, SFO)
Unload(C3, P3, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)

In Uninformed planning search for air cargo problem 2, the optimal plan is the breadth first search with less expanded node and goal tests. Depth first search instead took less time to be executed but expanded a huge number of nodes. Compared to problem 1, greedy best first graph search failed to find optimal plan this time.

For A* planning search, the optimal plan in term of the elapsed time is the one with h_pg_levelsum heuristics, but expands more nodes an goal tests compared to h_ignore_preconditions like mentioned for air cargo problem 1.

3. Air Cargo Problem 3:

Air Cargo Problem 3							
	Search Algorithm	**Expansions**	**Goal Tests**	**New Nodes**	**Plan length**	**Time elapsed**	**Optimality of solution**
uninformed planning searches	breadth_first_search	14663	18098	129631	12	75.1591	yes
	depth_first_graph_ search	408	409	3364	392	2.933969	No, It may find a non-optimal goal first
	uniform_cost_search	18151	18153	159038	12	103.3727	yes
	greedy_best_first_ graph_search with h_1	5398	5400	47665	29	27.1665	yes
A* planning searches	astar_search with h_1	18151	18153	159038	12	89.40742	yes
	astar_search with h_ignore_preconditions	5038	5040	44926	12	29.79163	yes
	astar_search with h_pg_levelsum	314	316	2894	12	325.2588	yes

Optimal plan:

Load(C1, P1, SFO)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P1, ATL, JFK)
Unload(C1, P1, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, ORD)
Load(C4, P2, ORD)
Fly(P2, ORD, SFO)
Unload(C2, P2, SFO)
Unload(C3, P1, JFK)
Unload(C4, P2, SFO)

For air cargo problem 3, the optimal uninformed planning search is again breadth first search with a plan length of 12. However, depth first search took less time to execute but with a huge plan length. Uniform cost search expanded more nodes and goal tests and took more time to execute.

A* planning search with h_ignore_preconditions, is optimal in term of the time elapsed but expanded more nodes and goal tests. Just like problem 1 and problem 2, h_pg_levelsum expanded less nodes but with the cost of taking more time to execute. A* Search video 30 in AIND Lectures explains that A* search will find the lowest cost path if the h function (estimate distance to the goal) for a state is less than the true cost of the path to the goal through that state. By ignoring preconditions, we are sure that the h function is optimistic and admissible to use it to find the lowest cost path.

For all air cargo problems, the A* planning searches performed better than the uninformed planning search to find the optimal plan. But for less space searches , uninformed planning search like in problem 1 and 2 perform well and may be preferred. In Breadth First Search Lectures of AIND, it is explained that Breadth first search finds the shortest path in terms of the least number of steps, but it will not find it in terms of total cost by adding up step costs. In uniform cost search lectures, the search expands more nodes than breadth first search since even after finding a path to the goal states it continues searching to try and find a cheaper path that also reaches the goal states.

The most efficient search method is A* search with ignore_preconditions heuristic because it ignore all preconditions witch reduce expanding ignored nodes and executes in less time.

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